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NUCLEAR ENGINEERING AND TECHNOLOGY

Original Article

HOT CELL RENOVATION IN THE SPENT FUEL CONDITIONING PROCESS FACILITY AT THE KOREA ATOMIC ENERGY RESEARCH INSTITUTE

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ARTICLE INFO

Article history:
Received 10 February 2015
Received in revised form
17 June 2015
Accepted 21 June 2015
Available online 12 August 2015

Keywords:
Advanced Spent Fuel Conditioning Process Facility
Hot Cell
Renovation
Teleoperation

ABSTRACT

Background: The advanced spent fuel conditioning process facility (ACPF) of the irradiated materials examination facility (IMEF) at the Korea Atomic Energy Research Institute (KAERI) has been renovated to implement a lab scale electrolytic reduction process for pyroprocessing. The interior and exterior structures of the ACPF hot cell have been modified under the current renovation project for the experimentation of the electrolytic reduction process using spent nuclear fuel. The most important aspect of this renovation was the installation of the argon compartment within the hot cell.

Method: For the design and system implementation of the argon compartment system, a full-scale mock-up test and a three-dimensional (3D) simulation test were conducted in advance. The remodeling and repairing of the process cell (M8a), the maintenance cell (M8b), the isolation room, and their utilities were also planned through this simulation to accommodate the designed argon compartment system.

Results and conclusion: Based on the considered refurbishment workflow, previous equipment in the M8 cell, including vessels and pipes, were removed and disposed of successfully after a zoning smear survey and decontamination, and new equipment with advanced functions and specifications were installed in the hot cell. Finally, the operating area and isolation room were also refurbished to meet the requirements of the improved hot cell facility.

1. Introduction

This report describes the renovation of the advanced spent fuel conditioning process facility (ACPF) operated by the Korea Atomic Energy Research Institute (KAERI). The ACPF, constructed in 2005, is located in the basement of the irradiated materials examination facility (IMEF) of Building 1 at the KAERI, shown in Fig. 1.

The ACPF is an alpha-gamma type hot cell with an air atmosphere. This hot cell consists of two cells: a maintenance

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http://dx.doi.org/10.1016/j.net.2015.06.013
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Fig. 1 – Aerial view of the irradiated materials examination facility (IMEF) at the Korea Atomic Energy Research Institute (the advanced spent fuel conditioning process facility located in the basement of the IMEF).

cell with a configuration of 2.2 m × 2.0 m × 4.3 m [length (L) × width (W) × height (H)] and a process cell with a configuration of 8.1 m × 2.0 m × 4.3 m (L × W × H). The wall of the hot cell is made of 0.9 m of heavy concrete to keep the dose rate < 0.01 mSv/h in the operating area. The isolation room located at the rear side of the hot cell is used to supply and retrieve materials and containers. Recently, the KAERI has refurbished the ACPF to demonstrate a lab scale electrolytic reduction process using spent nuclear fuel in an argon atmosphere. An additional argon compartment was constructed inside the process cell of the ACPF in order to study the electrolytic reduction process of a pyroprocessing technology [1]. Relevant remote handling systems and argon supplying systems were also implemented to make the argon compartment more functional. To accommodate the material transport and power management systems for the newly installed argon compartment, renovation works were performed on the working table, the entire frame supporting the working table, and a partial heating, ventilation, and air conditioning (HVAC) system inside the ACPF hot cell. The renovation of the isolation room involved dismantling all of the structural elements to accommodate raw materials from outside, and the construction of a new isolation room with a framework based on a newly designed crane system. In conjunction with the renovation of the hot cell and the supplementary facilities, renovation of the overall system, including the introduction of an uninterruptible power supply and an automated argon supply system, and of the in-cell crane used in the hot cell, was also performed. Fig. 2 shows schematic representations of the ACPF hot cell structure before and after the renovation. This report describes the entire renovation process in the chronological order of preliminary preparation, contamination measurement, decommissioning, dismantling, and treatment of the dismantled materials, and installation of new facilities. The approaches adopted or presented for each stage are expected to serve as reference data for similar renovation projects. This report can be used along with a previous research report on the cell renovation of the chemical processing facility of a high-level radioactive material research laboratory [2,3]. Additionally, technical reports from the IAEA, KAERI, and other institutes can be referred to for the decommissioning of reactor and hot cell facilities [4–12].

2. Preparation stage

2.1. *Basic guidelines for work safety*

Because the preparation stage takes place mostly in the hot cell, particular attention should be paid to radiation protection management and the prevention of hazard-material contamination of workers. The most efficient countermeasures against these kinds of work accidents and radiation exposures are minimization of workloads and working hours, as well as of intra-cell radiation levels. In this regard, we performed an initial decontamination of the hot cell inside the wall surface, followed by a surface contamination test and a second decontamination from the areas that did not satisfy the contamination standards specified by the KAERI. The effect of dose reduction as a result of the decontamination task was as follows. The cumulative radiation dose measured in a manager for the entire site who worked throughout the renovation work period of about 6 months, was ~330 μSV, which is ~0.45 μSV when converted to the daily average level (20 d/mo and 6 h/d). Undoubtedly, compared with the dose level of the manager, who was present at the site for the longest duration, the cumulative radiation dose of other workers, who spent considerably fewer hours at the site, can be assumed to be a much lower level. As per the radiation protection management protocol, these workers always carried a personal radiation dosimeter, and a computerized entrance control system maintained a daily record of working hours and cumulative exposure levels. These permissible radiation dose levels are attributable to the aforementioned decontamination pre-process measure that resulted in a reduction of intracell radiation levels. Another step in the preparation stage was the management of inside and outside work environments during the dismantling stage in the hot cell. Specifically, given the nature of the work-intensive dismantlement, involving cutting and grinding in the narrow space of the hot cell, extra ventilation equipment was installed and care was taken to set up a work schedule that ensures regular shift changes in order to minimize the physical burden on the workers. Table 1 outlines the problems encountered during the ACPF renovation and measures taken to address the problems. As shown in the table, we identified in advance the major high-hazard work items and established countermeasures at the planning stage of the entire work process.

2.2. *Preparations for hot cell refurbishing*

2.2.1. *ACPF mock-up simulation*

We applied three-dimensional (3D) computer-aided design to enable virtual prototyping in the design of equipment and in operability tests. The results of these preliminary tests were applied to the interference checks made on individual pieces of equipment and their final installation position, as well as in installation scheduling. Fig. 3 shows the schematic representations of the ACPF hot cell virtual prototype. They represent the expected post-renovation hot cell drawn before the completion of the renovation and were used for determining the positioning of each piece of supplementary

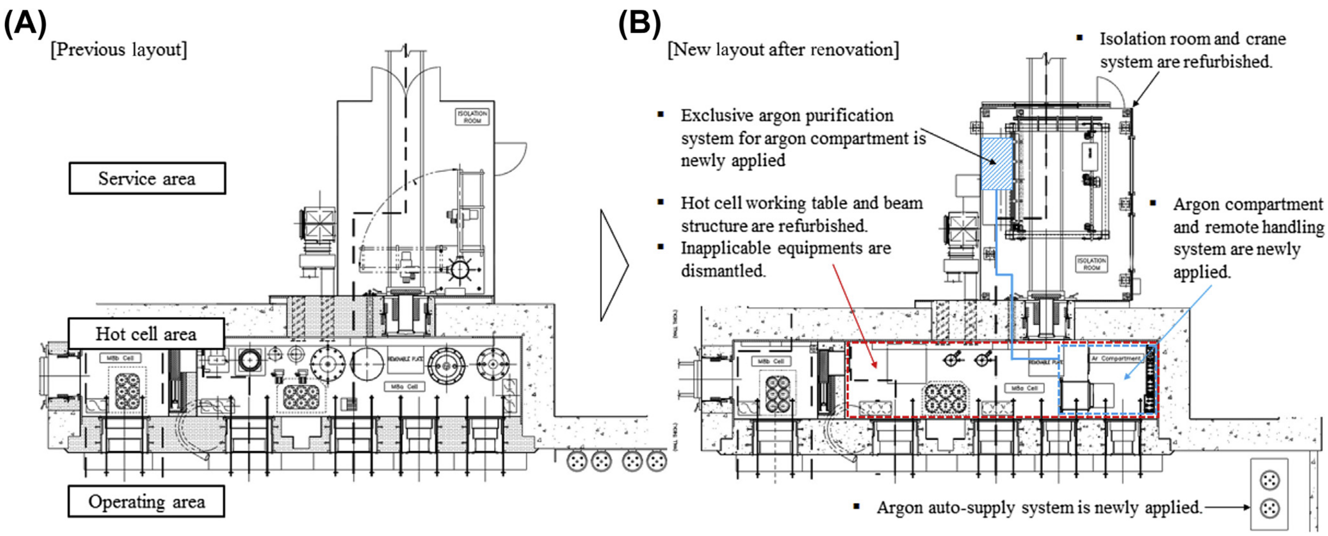

Fig. 2 – Schematic representations of prerenovation (A) and postrenovation (B) advanced spent fuel conditioning process facility.

equipment. The designs were also used for setting up the route for power and the HVAC system inside the new argon compartment.

2D and 3D computer-aided design systems were extensively used for the ACPF to perform the complex and multifaceted work processes in the renovation inside the cells and isolation room, such as equipment installation and waste disposal. Concrete work plans and schedules were set up based on the simulation results. Design, work processes, and the installation sequence of equipment were supplemented by a designer by verifying the operability with the applied remote handling systems.

2.2.2. *ACPF mock-up test*

In a separate zone, we installed a mock-up system that accurately represented the argon compartment to test and evaluate the positioning and remote control of the new equipment to be installed inside the argon compartment, which is the core process in the ACPF renovation. Using this mock-up system, we examined the remote controllability of the equipment as well as the raw material and equipment module entry route. With regards to the equipment installation, the following items were examined in detail to ensure work efficiency, work safety, and quality assurance: (1)

Table 1 – Advanced spent fuel conditioning process facility renovation-related issues and countermeasures.

Main issues	Dismantlement/ installation	Challenges	Solutions
Maximization of work efficiency inside the hot cell	Dismantlement	Excessive dust in a small space	- Extra ventilation equipment - Dismantling guide with image data
	Installation	Various kinds of construction materials have to be supplied through the restricted route sequentially	- Material entry route planning - Workforce allocation per waypoint to handle the materials safely
		Narrow working space	- Prefabrication
		Difficulty in locating equipment by relying only on drawings (subject to use-dependent modification)	- Mapping with mock-up and three-dimensional simulation
Minimal work hours inside the hot cell	Dismantlement/ Installation	Protection against radiation exposure of workers and working hours management in dust-intensive zones	- Setting up a worker pool and rotating shift work schedules
Safe waste disposal	Dismantlement	Large construction materials have to be dismantled and disposed of with special handling	- Interim space to store large pieces (1) Hot cell structures → interim storage in the isolation room (2) Isolation room structures → use of outside interim work space - Large shielded container for large size of waste materials

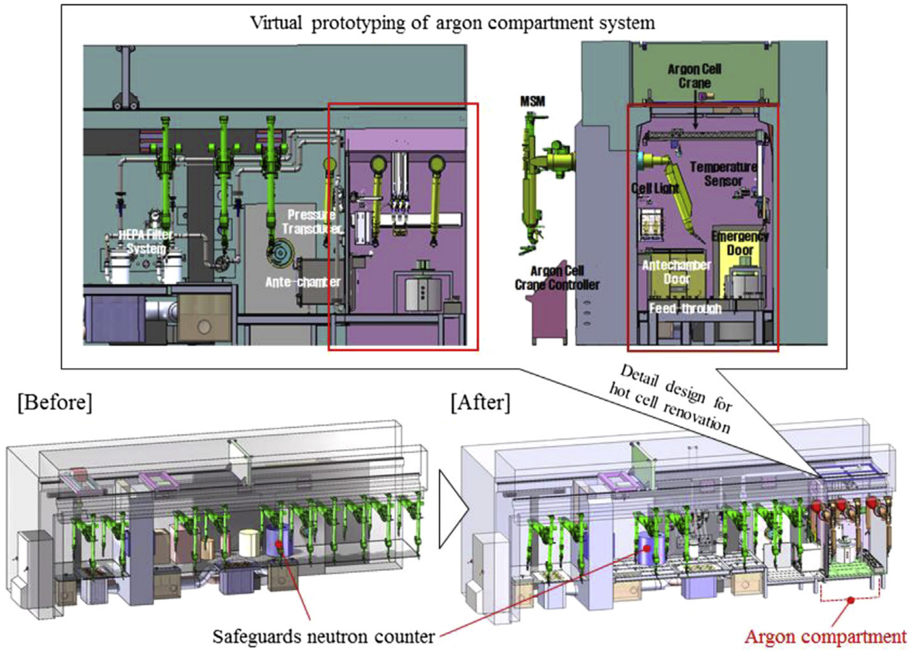

Fig. 3 – Advanced spent fuel conditioning process facility (ACPF) virtual prototype system representing expected postrenovation ACPF.

modularization of new equipment and module-by-module transportation and installation according to positioning plans; (2) prior simulation of the accessibility of remote handling systems with the mock-up facility to select the final installation positions, as shown in Figs. 4 and 5; and (3) multi-aspect examination of inter-unit interferences prior to final positioning with a 3D simulator. The argon compartment mock-up system shown in Figs. 4 and 5 was designed and built to implement the same argon environment as its actual counterpart to be installed inside the ACPF. For the safety and robustness of the argon environment, it is critical to sustain a high level of airtightness to prevent argon leakage into the remaining ACPF space by oxygen-filled circulating air. Leakage tests validated the airtightness. Finally, the argon compartment of the ACPF was constructed according to the same specifications and building procedures as its mock-up counterpart.

2.3. *Measures for dismantling plan, contamination measurement, decontamination, and waste packaging*

2.3.1. *Management of dismantling facilities according to zone*

As mentioned in Section 2.1, surface contamination measurements were made prior to the dismantling of the equipment and piping in the ACPF. This section describes in detail the measures and approaches taken. Fig. 6 shows the predismantling work for the hot cell contamination test and the decontamination. Specifically, we divided the objects involved in the dismantling plan into manageable related zones to facilitate the contamination measurement and

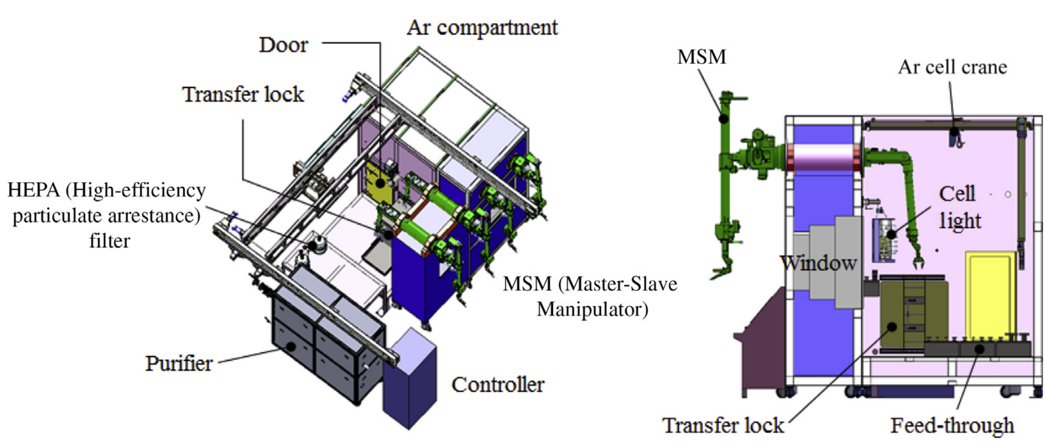

Fig. 4 – Argon compartment mock-up system layout mimicking the advanced spent fuel conditioning process facility argon compartment.

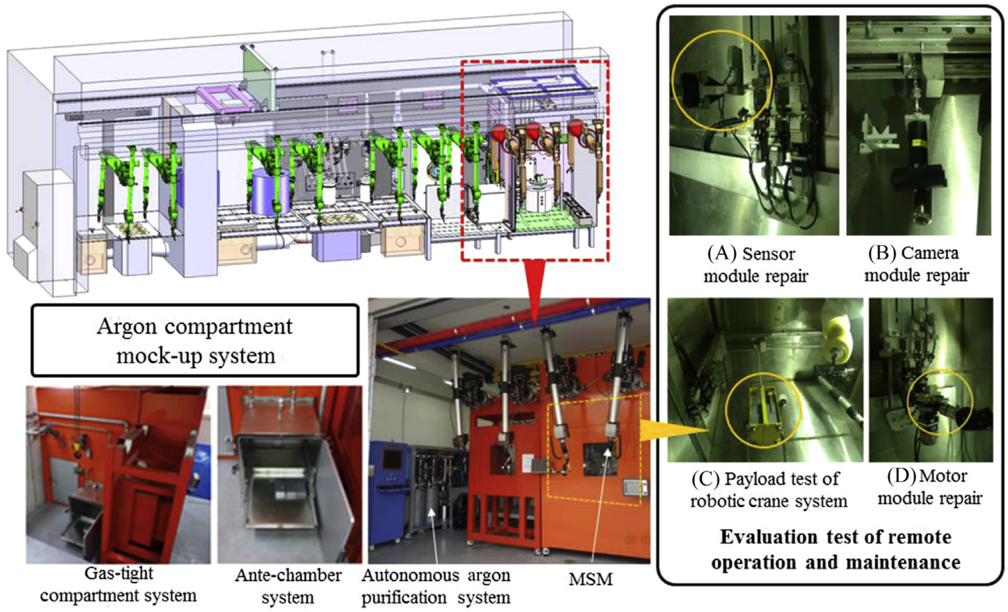

Fig. 5 – Development of argon compartment mock-up system and remote controllability test of installed equipment.

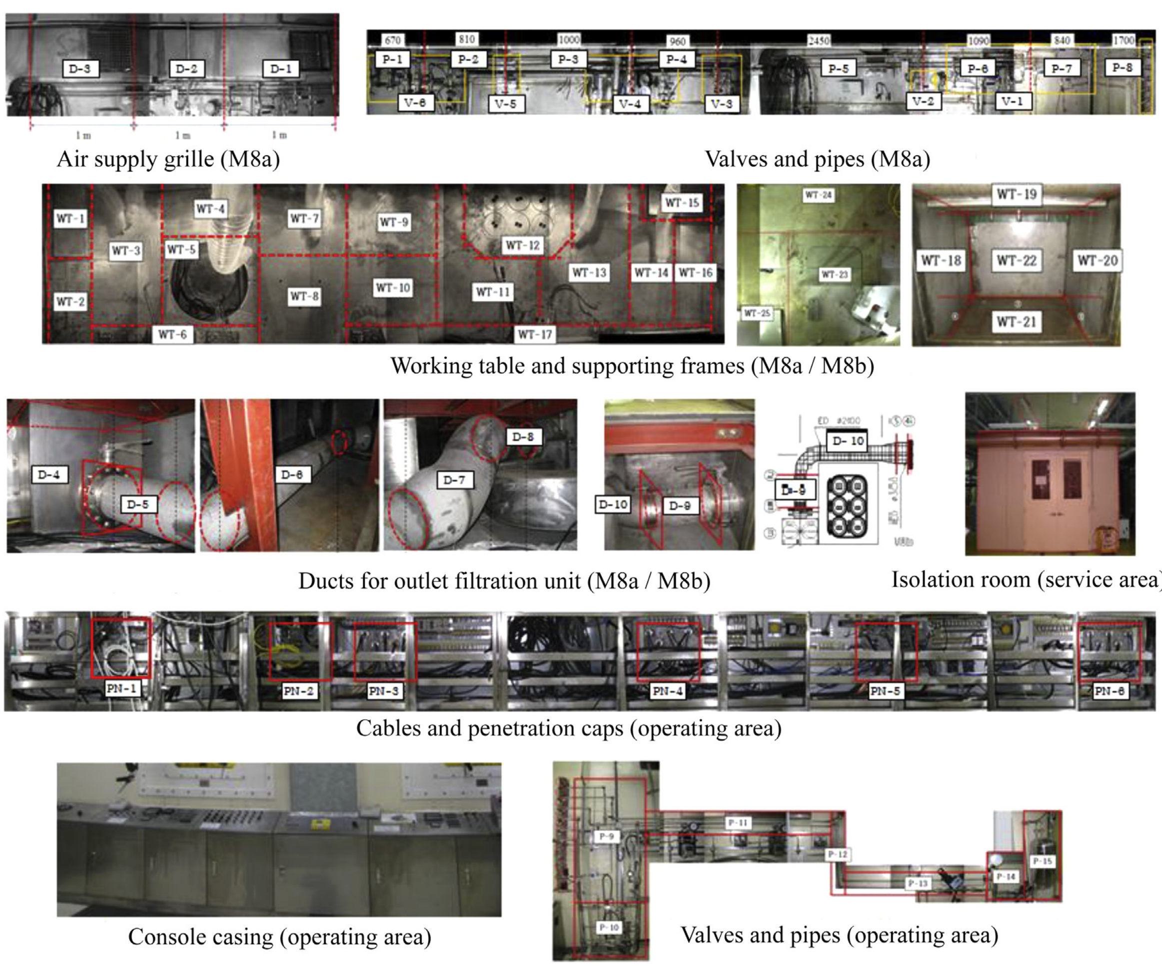

Fig. 6 – Considered samples of zoning and labeling of hot cell and supplementary facilities in preparation for contamination measurement and dismantling work.

decontamination task. Through the zoning and labeling of specific surfaces and objects, they can be easily identified and managed in case of a second decontamination and contamination retest of individual parts.

Fig. 7 shows the practically considered list of dismantled objects itemized by type and location. This list was very useful in managing the results of the contamination measurement according to zone.

2.3.2. *Waste management, packaging, and transportation*

While dismantling structural elements inside and outside the ACPF hot cell, a large amount of large-sized H-beams, panels, and scrap metals should be properly disposed of. These waste materials are fundamentally different from those originating from clean areas and therefore need to be handled differently. The majority of waste materials including textiles (working clothes and gloves) and test by-products from radiation controlled areas, e.g., the hot cell, are combustible, and are typically packaged in special purpose 200 L drums and transported. Because this commonly used disposal process cannot be applied to the atypical waste materials that are generated in large quantities on special occasions such as hot cell renovation, they should be handled by setting up different procedures and methods. The following briefly describes how we managed this special case of disposal of atypical waste materials generated in radiation controlled areas. First, we divided the means of transportation into three categories: (1) a 4,000 L container for interim storage of the dismantled structural elements and large metal pieces; (2) individual transportation of heavy shielding vaults, which were individually wrapped after hot cell decontamination and surface contamination testing; and (3) 200 L sealed drums for the storage and transport of the remaining combustible waste. In particular, the use of a large shielded container was extremely useful in minimizing the physical dismantling workload inside the hot cell zone, thus improving the work environment for the workers by reducing the fugitive dust level. It should be noted that all these dismantled structural elements were handled and treated in compliance with the pertinent regulations specified by the safety control agency, by performing a multi-step contamination test and decontamination task, and their radiation levels satisfied their respective safety

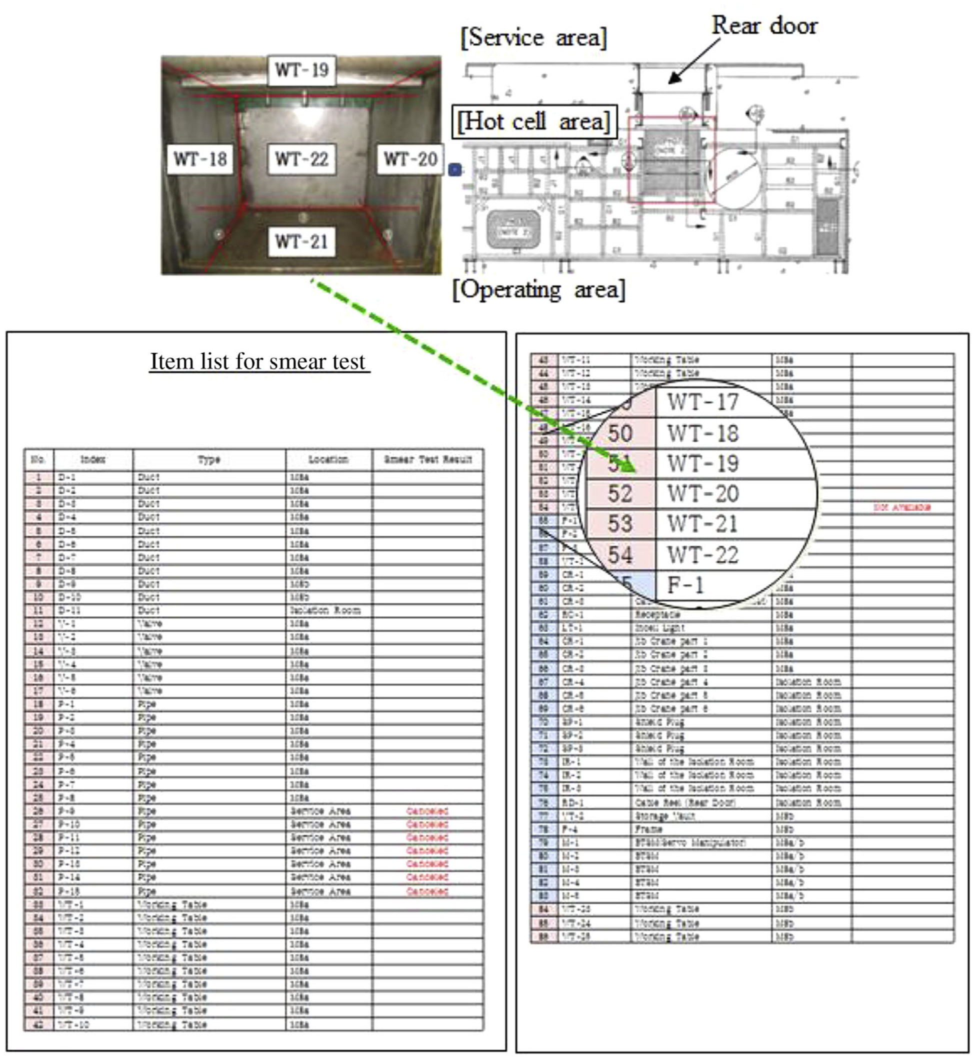

Fig. 7 – Surface contamination measurement sheet with zoned and labeled items of dismantled objects.

requirements. The radiation dose level of the workers was regularly monitored by sampling personal protection devices worn by them during the work. Fig. 8 shows the entire process of waste management.

3. Hot cell renovation

3.1. *Strategy for dismantlement*

As described above, the primary focus of the ACPF renovation was the remodeling of a hot cell to realize the modified electrolytic reduction process, as well as the structural modification of facilities to enable the new equipment to operate. The scope of renovation included the ACPF itself, the operating area from which the equipment inside the hot cell are operated and controlled, and the isolation room behind the hot cell that serves as a buffer zone designed to provide allowable protection to the workers from radiation exposure in the event of opening the rear door of the hot cell. These zones have their respective management levels so that inter level material movements are strictly controlled, and workers should change their clothes whenever they pass from one zone to another. During renovation, however, all waste materials generated in each zone had to be transported from the sites through the IMEF-ACPF hatch, which made it necessary to move materials across zones. To minimize the low level zone contamination during such material movements, we opened all the doors of each zone and covered the floor with a protection sheet. Additionally, important facilities that were not part of dismantling were covered for protection and the existing isolation room was used as an interim working space to reduce the size of large materials dismantled from the hot cell to sizes that can be transported. This prevented unnecessary dispersion of dust into the hot cell space and outside the isolation room. Fig. 9 describes the floor plans of the IMEF and ACPF, their interconnection, and the material transport routes used during dismantlement.

3.2. *Surface contamination test and decontamination from dismantling objects*

Prior to dismantling, all dismantled parts underwent an initial decontamination process, as shown in Fig. 10, and, following the zoning and labeling process, a contamination test, as illustrated in Figs. 6 and 7. The contamination measurement results were assessed by zone, and a decontamination task was performed on the zones that needed further decontamination; this was followed by a reassessment of the test results. Finally, all dismantled parts were thus decontaminated and prepared for dismantling.

3.3. *Dismantling task*

After the sites were decontaminated, workers entered the hot cell and dismantled considered parts. Detailed monitoring of contamination and radiation dose levels was conducted whenever the workers entered and left the cell. Extreme care was taken to prevent spreading of contamination during waste material transportation. The radiation level inside the hot cell was maintained at 0.15 mSv/h or lower, which is a sufficiently low level for intra-cell radiation. Fig. 11 is a schematic representation of the entire dismantling process.

All dismantled materials ready for transportation were categorized into combustible and noncombustible materials; the combustible wastes and small noncombustible wastes

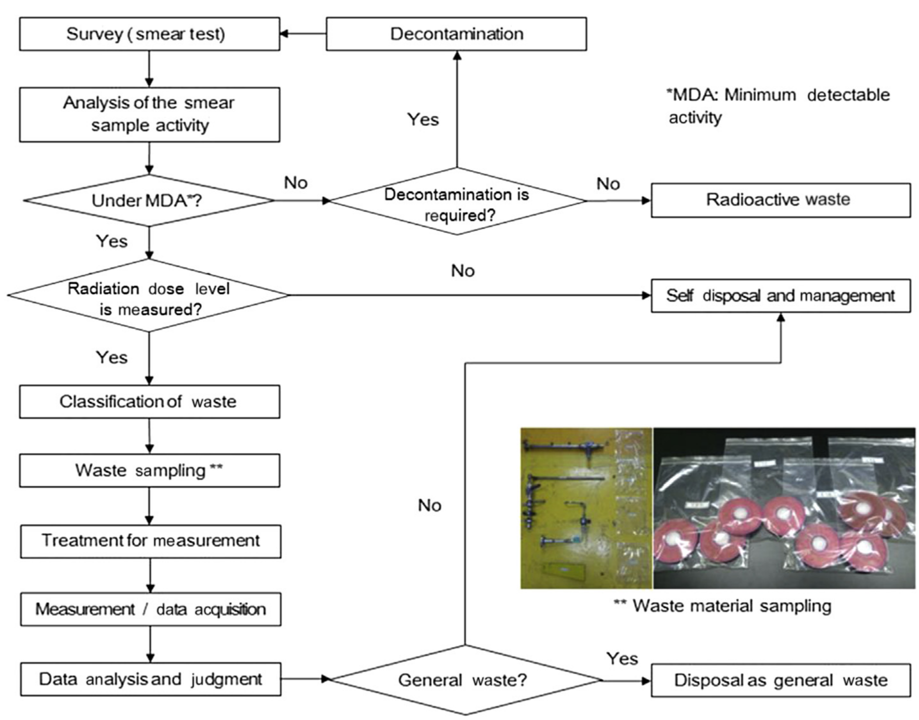

Fig. 8 – Waste disposal flowchart for decontamination, contamination test, packaging, and transport.

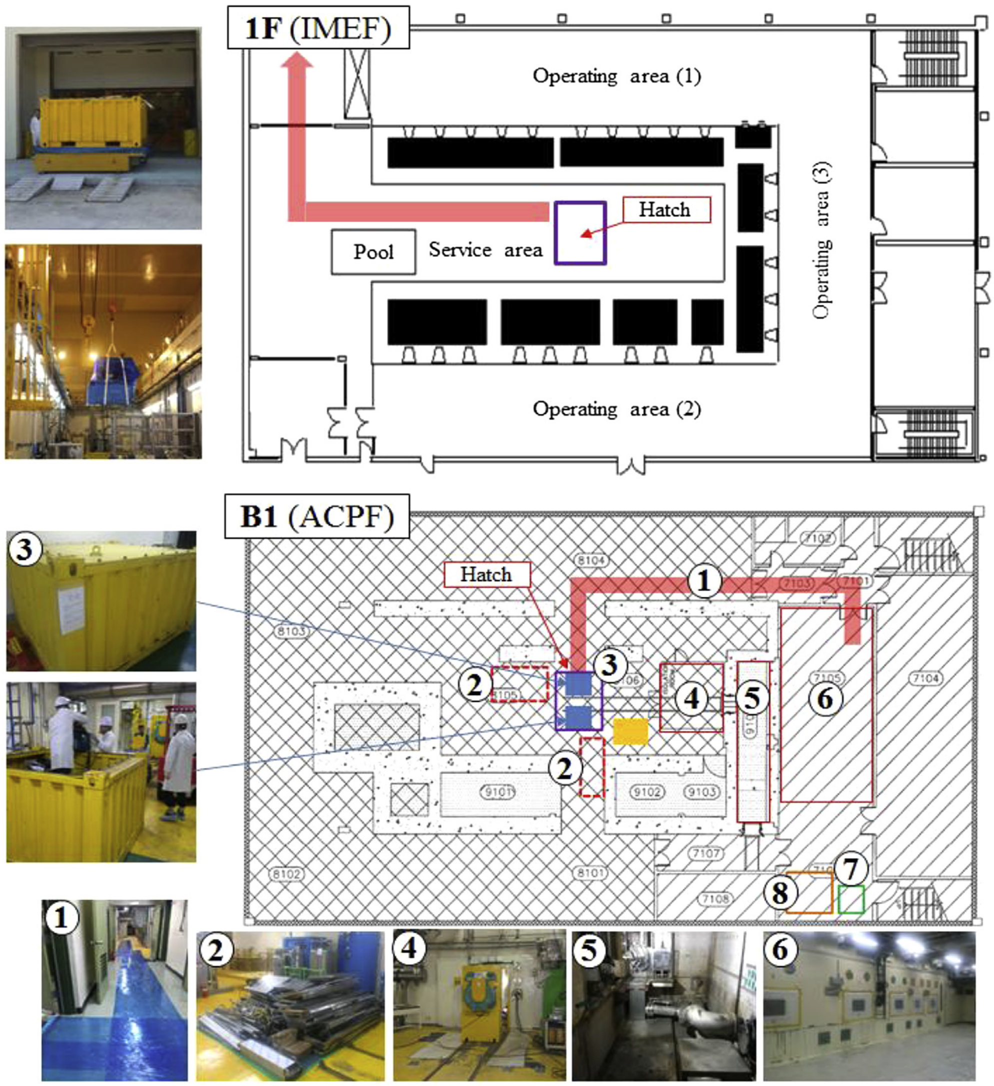

Fig. 9 – Material transportation routes for the advanced spent fuel conditioning process facility (ACPF) renovation [irradiated materials examination facility (IMEF)-ACPF].

Fig. 10 – Hot cell wall decontamination on hot cell interior walls, existing facilities and waste containers.

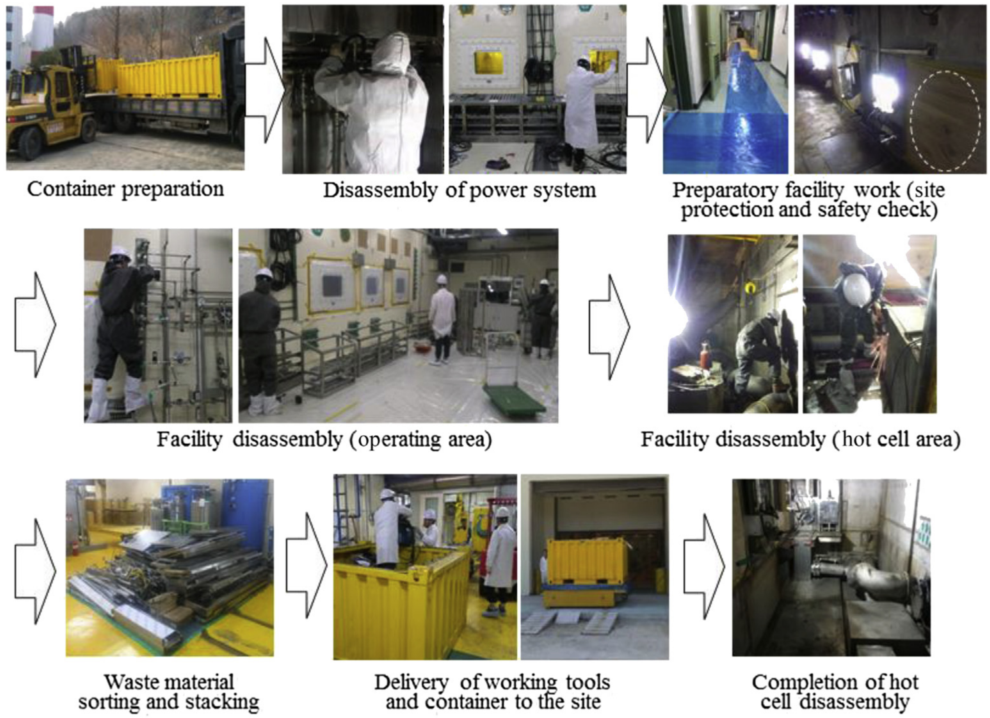

Fig. 11 – Overview of the advanced spent fuel conditioning process facility dismantling process.

were put into waste drums, and large noncombustible pieces were stacked in a large shielded container (Fig. 12).

4. Renovation in hot cell area

4.1. *Renovation inside hot cell (air zone)*

Fig. 13 shows the major changes in the hot cell air zone. The two pictures, taken before and after the renovation, reveal that all existing processing equipment was removed and that the argon compartment was constructed within the hot cell with a separate power supply and HVAC system.

4.2. *Construction of argon compartment*

The argon compartment constructed within the hot cell (ACPF M8a) is an argon atmosphere zone separated from the other parts of the ACPF hot cell (air zone). A transfer lock system was installed, as shown in Fig. 14, to ensure an intact argon environment in the argon compartment during the entry and exit of all necessary material transport containers and equipment. The maximum size that can be handled by the transfer lock system is 600 mm × 600 mm × 600 mm. We also installed electrolytic reduction processing equipment and shielded transport containers as well as a robotic crane, monitoring camera, and lighting systems necessary for their operation [13]. In particular, the in-cell camera and lighting systems were designed such that an operator can detach and replace them using a remote handling system from the operating area.

As shown in Fig. 15, the robotic crane system installed in the compartment is specially designed to perform the remote operation of modularized process equipment and maintenance for process equipment modules such as Master-Slave Manipulator (MSM), camera, cell light and sensors [14].

4.3. *Refurbishment of the hot cell crane system*

Due to the construction of the argon compartment, the existing cable route could not be used for the in-cell crane

Fig. 12 – Three packaging types of waste dismantled from the advanced spent fuel conditioning process facility. (A) Individual packaging, (B) large shielded container, and (C) drums.

Fig. 13 – Pre- and postrenovation hot cell interior.

system operated inside the hot cell and for the gate crane necessary for its maintenance and repair. To solve this problem, additional cabling and cable connections around the argon compartment were necessary. The cable used for the hot cell was a custom-made radiation resistant one, thus it was not easily available. We solved this problem by changing the direction of the power supply cable connected to the motor that drives the entire crane system by 180°, as shown in Fig. 16. This simple maneuver enabled us to lay out a new cable route using the existing cable.

5. Renovation in isolation room area

5.1. *Radiation protection for the isolation room*

For the operational protection of outside workers, the following assumptions are made for the design of the shielded wall and windows of the isolation room as shown in the right side of Fig. 17. First, the working condition behind the wall is considered. That is, the predefined dose rate of a radiation source contained in the PADIRAC shielded door of the ACPF is assumed to be 10 mSv/h and the permissible dose rate on the designed shielding wall is considered to be 0.1 mSv/h. Second, the dose rate of the virtual radiation source (16×16 PLUS7, 1 kg) on the designed wall is simulated and the conversion factor is determined. For example, if the dose rate on the wall is 583.87, then the conversion factor is calculated as $10/583.87 = 0.01713$. Through this process, the regulated virtual source is acquired, which affects the dose rate of 10 mSv/h on the designed wall. Finally, the expected dose rates can be simulated for different materials according to their thickness. Table 2 lists the calculated dose rates for several candidate materials for the shielded wall. QAD-CGGP-A is utilized as the calculation code. As listed in Table 2, a 5 cm thick steel plate and 6 cm thick lead glass pane were selected as the materials for the shielded wall and shield window, respectively, to satisfy the permissible dose rate of 0.1 mSv/h behind the shielded wall of the isolation room. Fig. 17 shows the renovated isolation room and the changed structure of the crane system.

5.2. *Renovation of the crane system in the isolation room*

A jib crane was installed and operated in the old ACPF isolation room, but the lift height of this jib crane was not sufficient

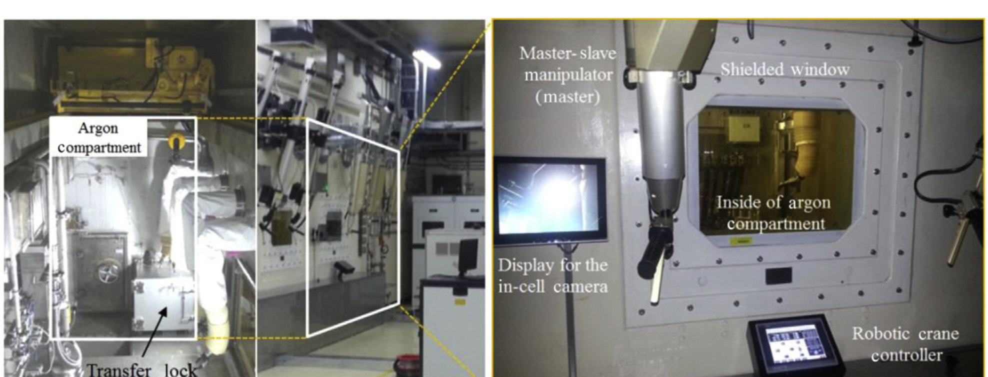

Fig. 14 – Argon compartment zone in the advanced spent fuel conditioning process facility.

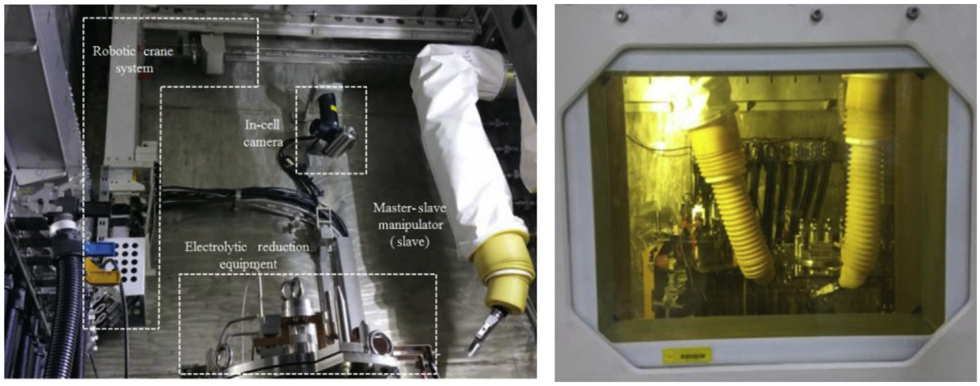

Fig. 15 – Argon compartment operation system: electrolytic reduction equipment, in-cell camera, and robotic crane system.

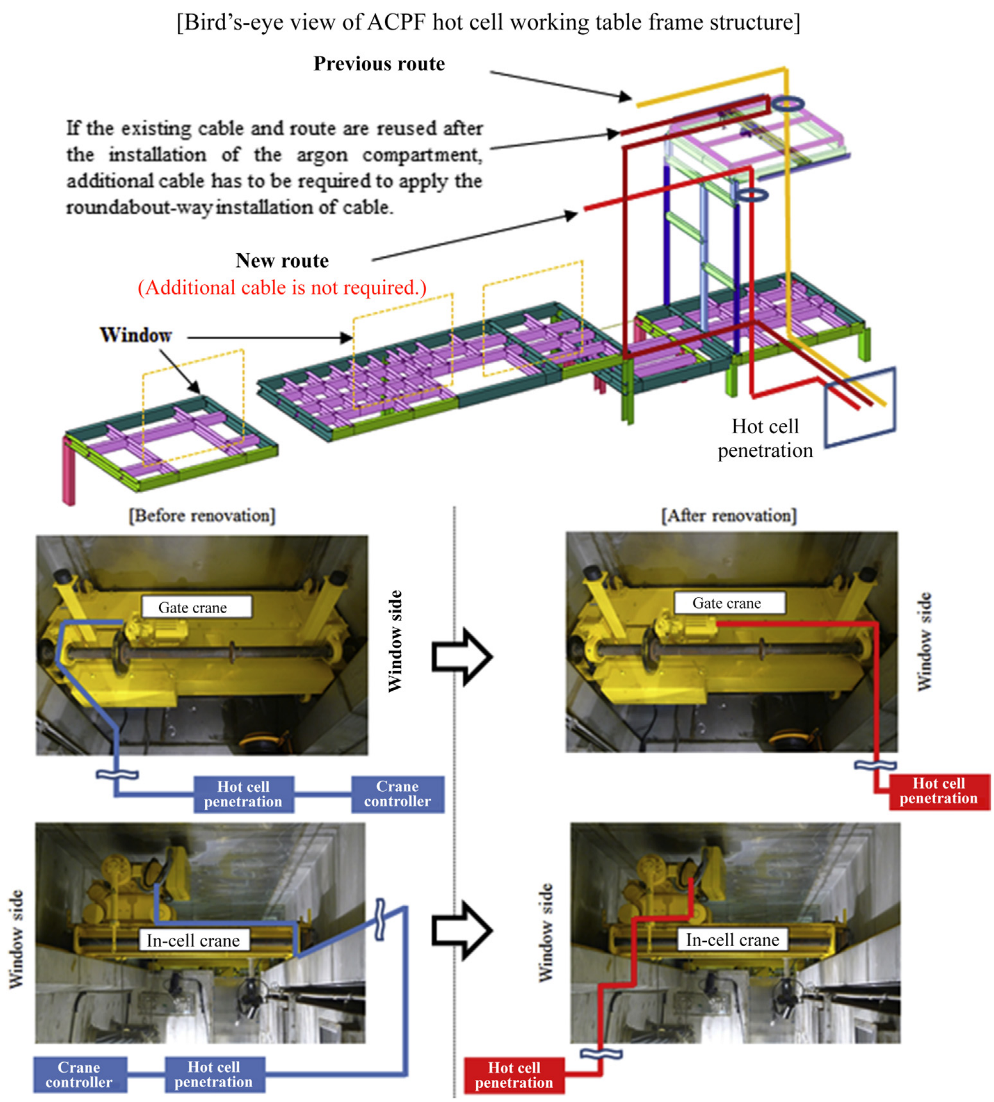

Fig. 16 – Cost reduction by changing the cable route of the existing power supply and signal-transmission cable for the crane system. ACPF, Advanced Spent Fuel Conditioning Process Facility.

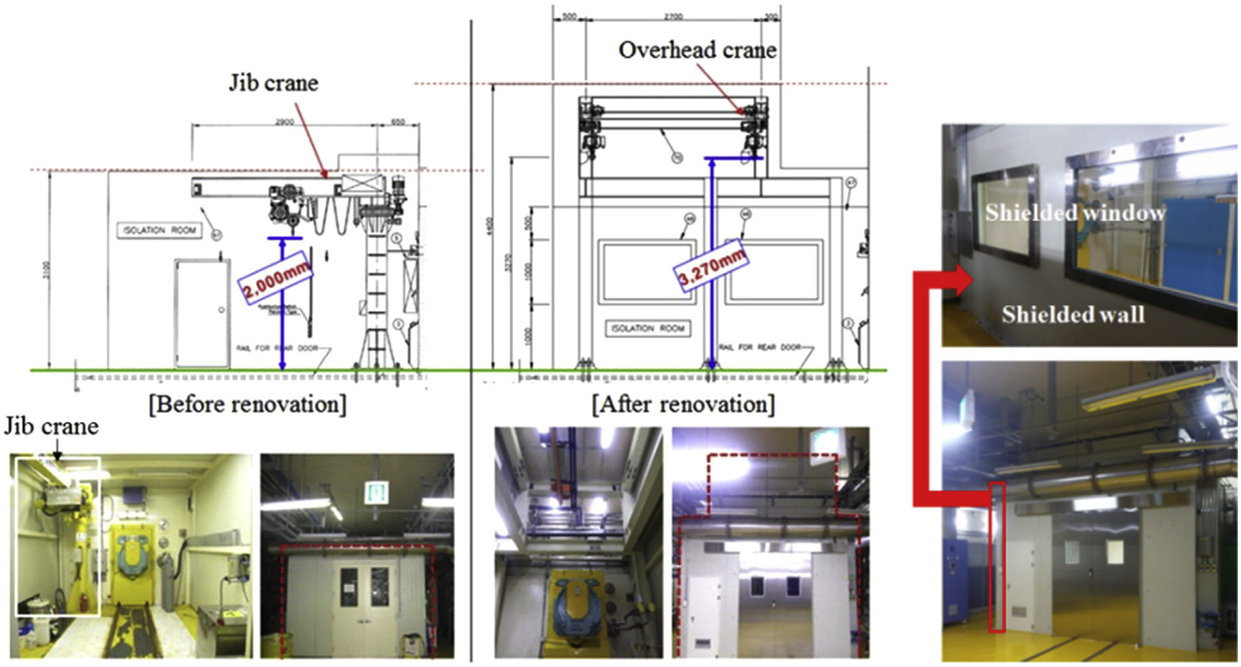

Fig. 17 – Renovated isolation room and changed structure of the crane system.

to accommodate the new shielded containers. As shown in Fig. 18, the first shielded container could not be loaded in the second shielded container if the previous jib crane system were to be applied.

Moreover, the second shielded container is a high-load container that cannot be unloaded from the transport trolley. This posed a challenging problem in that it could not be handled by the crane inside the isolation room. Even if the second container could be taken off the trolley, there was still the constraint of fabricating the lift chain of ~400 mm length. To address these problems, we increased the overall height of the isolation room ceiling in the new design, thereby modifying the old jib crane into a gantry crane. The new gantry crane outperformed the old jib crane in lift height by ~63.5% while retaining ~94% coverage (Fig. 19).

6. Renovation in the operating area

Processing equipment within the hot cell and other supplementary facilities, are operated remotely from an outside operating area using telemanipulator and crane systems, and the status inside the hot cell is monitored simultaneously using a radiation-hardened camera and a pressure/temperature measurement system. The convenience of work in the

Table 2 – Shielded dose rate according to the different kinds of considered materials [radiation source: 16 × 16 plus7 (1 kg); distance from the source to the target position: 30 cm, calculation code: QAD-CGGP-A].

Material	Concrete	Material	Steel	Lead	Lead glass	
Density / Thickness	2.33 g/cm^3	Density / Thickness	7.86 g/cm^3	10.3 g/cm^3	4.12 g/cm^3	5.2 g/cm^3
10 cm	0.154	2 cm		0.1613		
11 cm	0.126	3 cm	0.2167	0.0706		0.2866
12 cm	0.109	4 cm	0.1342	0.0328		0.1959
13 cm	0.0904	5 cm	0.0817	0.0162	0.1980	0.1320
14 cm	0.0759	6 cm	0.0502		0.1468	0.09056
15 cm	0.0640	7 cm	0.0311		0.1074	0.06135
20 cm	0.027	8 cm	0.0192		0.0792	0.04205

Unit: mSv/h.
Bold letters mean final selections.

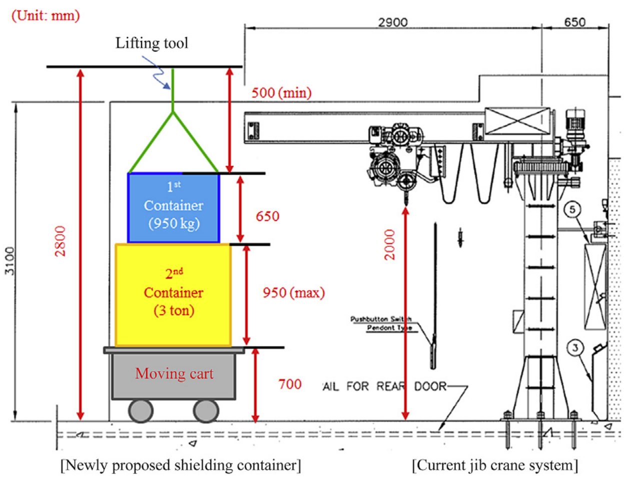

Fig. 18 – New requirement of minimum lift height for modified shielded container handling.

Fig. 20 – Pre- and postrenovation of argon supply system.

hot cell was improved by a wireless hand-held crane control system, which could be handled freely in the operating area. Moreover, many kinds of supplementary systems for the hot cell were introduced in this area including the following equipment. An uninterruptible power supply system and a new automatic control-based argon supply system were newly installed in this area to ensure the operational consistency of the argon compartment system (Figs. 20 and 21).

Fig. 22 shows the refurbished operating area of the ACPF. Five pairs of MSMs are installed on the hot cell wall, and a laser-induced breakdown spectroscopy (LIBS) system is installed on the M8 cell and connected to the controller through a penetration in the wall. The LIBS system is laser-based equipment that uses a focused pulse laser beam to generate microplasma. The emission from the plasma is wavelength resolved using a spectrograph, detector, and computer system to determine the elemental composition of the samples of interest.

LIBS, laser-induced breakdown spectroscopy; MSM, master-slave manipulator; UPS, uninterruptible power supply.

7. Discussion

This report describes a series of work processes implemented for the renovation of the ACPF in the radiation controlled areas of the KAERI. The following concluding statements can be made about the ACPF renovation.

First, possible errors during renovation were prevented by performing a 3D image simulation and mock-up test of new facilities and by proactively applying the results to the actual work.

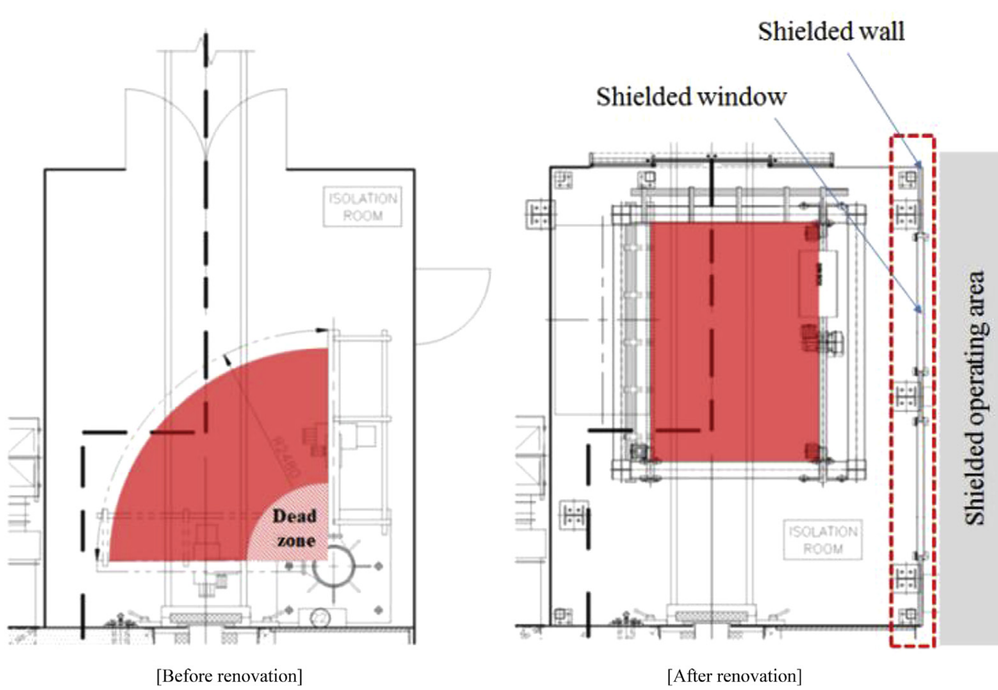

Fig. 19 – Coverage comparison between old and modified crane systems: 63.5% increased lift height while retaining 94% coverage after renovation.

Fig. 21 – Uninterruptible power supply system ensuring stable power supply even during facility power-off hours.

Second, during the dismantling task in the hot cell, we could minimize workloads while keeping the dispersion of fugitive dust and contaminants at the lowest possible levels through differentiated packaging of the dismantled materials according to size before transportation. Radiation dose levels in the facilities could also be minimized through systematic contamination tests and decontamination through prior zoning and coding of all dismantling objects. Furthermore, individual radiation dose levels of all workers were monitored daily using protection device sampling and personal radiation dosimeters, and their working hours were regulated by setting up rotating shift work schedules.

Third, radioactive waste generated during the dismantling task was sorted by type and loaded in special shielded containers for safe transportation. Safe waste management was ensured by performing in advance multi-aspect decontamination measures, such as smear tests, post-packaging surface contamination tests, and individual component measurements of sampled waste materials.

Fourth, the planned work could be completed successfully without any accident by employing safety-checked processing methods during the entire renovation period.

The results of the renovation task suggest that it is critical to perform a sufficient preliminary investigation and verification to prevent accidents at the sites that are subject to strict on-site monitoring requirements. Specifically, mock-ups should be employed to ensure the proper handling of actual facilities and equipment. Despite the additional work required in comparison with general design and work preparations, sufficient preliminary measures should be taken, considering that having to manage unexpected on-site situations was not uncommon. Through this renovation work, a large amount of data has been accumulated on decontamination and safety measures associated with facility dismantling and waste disposal. These data are expected to serve as a useful reference for future renovation and improvement projects of similar facilities and hot cells, and thus contribute to safe and rational project implementation. In the successfully renovated ACPF, facilities will be operated with a view to developing an advanced electrolytic reduction technique through actual experiments.

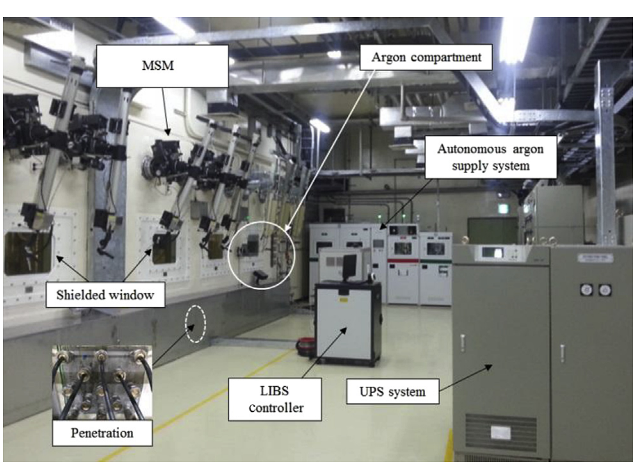

Fig. 22 – Refurbished operating area of the advanced spent fuel conditioning process facility.

Conflicts of interest

All authors have no conflicts of interest to declare.

Acknowledgments

This work was supported by the Nuclear Research and Development Program of the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (MEST).

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